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Seismic Performance Evaluation of Mid-Rise Concrete Buildings Equipped with Lead Rubber Bearings Using Fragility Curves

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ABSTRACT

This study evaluates the seismic performance of mid-rise concrete moment-resisting frames (MRFs) equipped with lead rubber bearings (LRBs) using fragility curves. Two concrete buildings (8- and 12-story) were designed with and without LRBs in SAP software. Critical sections and stress ratios of structural members were extracted, and a representative 2D frame was modeled in Open Sees. Incremental Dynamic Analysis (IDA) was performed using 10 ground motion records, and fragility curves were derived based on inter-story drift ratios. Key findings include:

- The LRB system significantly increased the structural period, with amplification factors of 2.22 and 2.17 for the 8- and 12-story buildings, respectively.
- LRBs reduced inter-story drift by 14.3% (8-story) and 18.5% (12-story), enhancing seismic stability.
- Structures with LRBs tolerated higher peak ground acceleration (PGA) before reaching failure thresholds.
- The probability of earthquake-induced damage decreased by 11.8% (8-story) and 25.75% (12-story), indicating superior LRB effectiveness in taller buildings.

These results highlight LRBs' potential to mitigate seismic risk in mid-rise concrete structures, particularly in high-rise configurations.

Keywords: Mid-rise concrete buildings; Lead Rubber Bearings (LRB); Incremental Dynamic Analysis (IDA); Fragility curves; Structural period; Inter-story drift.

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1. INTRODUCTION

The proliferation of mid-rise concrete buildings in urban Iran, coupled with the country's location in a seismically active region, necessitates rigorous seismic performance

assessments. Earthquakes pose significant threats to structural integrity, underscoring the importance of energy dissipation systems such as base isolation. This study focuses on evaluating LRB-equipped

mid-rise concrete buildings, through fragility curves a critical tool for quantifying seismic vulnerability.

Conventional seismic design assumes substantial earthquake forces are transmitted to structures, requiring high resistance capacity. In contrast, seismic base isolation aims to decouple the structure from ground motion via a flexible interface between the foundation and superstructure. This system reduces transmitted forces, limits inter-story drift and enhances energy dissipation. LRBs, a type of elastomeric isolator with a lead core, provide both vertical stiffness and horizontal flexibility, balancing force reduction with displacement control [1]. By elongating the structural period, LRBs lower spectral acceleration demands, thereby reducing inter-story drift and damage risk.

Despite these benefits, the performance of LRBs in mid-rise concrete buildings particularly under varying heights remains underexplored. This study addresses this gap by quantifying LRB effectiveness in 8- and 12-story frames using IDA and fragility curves. The outcomes aim to inform design practices, reduce economic losses, and enhance life safety in seismically vulnerable regions.

1.1. Lead Rubber Bearings (LRBs)

LRBs consist of a lead core encased within a laminated rubber bearing. While conventional elastomeric isolators lack sufficient damping capacity, the inclusion of the lead core enhances energy dissipation by increasing the damping ratio from approximately 3% (for pure rubber bearings) to over 10% through hysteretic yielding of the lead during seismic excitation. Additionally, the lead core provides initial stiffness to resist low-intensity lateral loads (e.g., wind or minor earthquakes).

A critical design parameter for LRBs is the effective dynamic shear modulus (G). Based on the FIP Industrial catalog (Italian manufacturer), LRBs are categorized as:

-Type S: $G = 0.4 \text{ MPa}$

-Type SN: $G = 0.6 \text{ MPa}$

Geometric and mechanical parameters including maximum vertical load (seismic and operational), effective horizontal stiffness, equivalent viscous damping ratio, yield stress, vertical stiffness, elastomer outer diameter, and elastomer thickness

are defined for displacement ranges of 100–400 mm for both LRB-S and LRB-SN types.

1.2. Fragility Curve Formulation

When empirical failure data or sufficient ground motion records are unavailable, analytical fragility curves derived from numerical simulations or stochastic structural analyses provide a robust alternative for assessing seismic vulnerability. Fragility curves quantify the probability of exceeding predefined damage states (e.g., yielding, collapse) as a function of seismic intensity. This probability is expressed as:

$$Pf = \left[\frac{D}{C} \right] \geq 1 \quad (1)$$

$$Pf = \Phi \left(\frac{\ln \frac{Sd}{Sc}}{\sqrt{\beta d^2 + \beta c^2}} \right) \quad (2)$$

where:

D: Seismic demand (e.g., inter-story drift, floor acceleration).

C: Structural capacity.

Sc: Median capacity for a specific damage state.

β_{total} : Total logarithmic standard deviation (accounting for demand and capacity uncertainties).

Φ : Standard normal cumulative distribution function.

Fragility curves are typically modeled as log-normal distributions, aligning with central limit theorem assumptions when demand and capacity follow normal or log-normal distributions [1].

1.3. Literature Review

Kumar (2015) investigated the effects of soft-story behavior on fixed-base and LRB-isolated reinforced concrete buildings [2]. Focusing on the response of soft-story reinforced concrete frames under various seismic loads, four structural models were designed to analyze the influence of soft-story behavior. Time-history dynamic analysis using Ruaumoko software revealed the impact of soft stories on fixed-base and LRB-isolated systems. Key parameters, including system period, floor accelerations, inter-story drift ratios, base shear, and plastic hinge distribution, were evaluated. Li et al. (2013) explored the limitations of the height-to-width ratio for buildings isolated with elastomeric bearings [3]. Numerical results indicated that soil type significantly affects the critical height-to-width ratio for elastomeric

isolation systems. Softer soils reduced this ratio for varying seismic intensities, while higher fundamental periods in isolated buildings allowed for larger height-to-width ratios. Ozer et al. (2022) compared the seismic behavior of LRBs and Friction Pendulum Systems (FPS) under torsional effects [4]. Nonlinear analyses of base-isolated reinforced concrete buildings with LRBs and single concave FPS isolators highlighted LRBs' greater sensitivity to torsional irregularities. Nonlinear member behavior was incorporated, demonstrating that LRBs exhibit higher torsional vulnerability than FPS isolators. Zhu et al. (2018) studied the cyclic behavior of metallic yielding dampers [5]. Their findings emphasized the importance of damper yield displacement as a key design parameter. A proposed algorithm for uniform ductility demand across stories in steel moment frames (3-, 5-, and 10-story) reduced damage indices and improved energy dissipation. Komur et al. (2011) conducted nonlinear dynamic analyses on fixed-base and LRB-isolated reinforced concrete structures [6]. Two 4- and 8-story buildings were designed, confirming the advantages of base-isolated systems in reducing seismic demands compared to fixed-base structures. Nassani and Abdulmajeed (2015) evaluated base isolation systems in reinforced concrete structures [7]. Their research underscored the effectiveness of isolation systems in mitigating seismic responses, such as floor accelerations and inter-story drifts, through advanced analytical techniques. Shoaee and Mahsuli (2019) developed a reliability-based design framework for steel moment frames with LRBs [8]. Modeling the system as an equivalent two-degree-of-freedom system, they incorporated uncertainties in superstructure mass and stiffness using probability density functions. Providakis (2008) analyzed LRB-equipped structures with viscous dampers under near-fault earthquakes [9]. Nonlinear time-history analyses using commercial software demonstrated the damping effects of LRBs on base and superstructure buckling. Tavakoli et al. (2015) assessed the role of LRBs in enhancing lateral resistance against progressive collapse [10]. Results

indicated that base isolation localizes damage to isolated areas, preventing propagation to intact structural components, though it does not significantly improve resistance under gravitational loads. Yaktine et al. (2023) examined LRBs and viscous dampers in irregular reinforced concrete buildings [11]. Nonlinear dynamic analyses of 3-, 8-, and 20-story structures showed LRBs reduce peak floor acceleration, inter-story drift, and base shear. Pahlavan et al. (2019) probabilistically evaluated the seismic vulnerability of RC frames retrofitted with steel jacketing [12]. Field studies on buildings in northern Iran revealed significant improvements in median fragility values for retrofitted models. Zamani Bidokhti and Kohestanian (2021) assessed soil-structure interaction (SSI) effects on base-isolated concrete buildings [13]. OpenSees models of 4-, 8-, and 12-story LRB-isolated structures on soft, medium, and stiff soils showed SSI amplifies roof accelerations in shorter buildings but increases base shear in taller ones. Fehimi Farzam and Yousefi (2023) probabilistically evaluated LRB-isolated steel moment frames [14]. Using OpenSees and 22 far-field records from FEMA P695, collapse margin ratios increased by 100% (3-story) and 81% (9-story), highlighting superior performance in low-rise structures. Farsangi (2021) analyzed fragility of non-ductile RC buildings with LRBs under orthogonal ground motions [15]. While LRBs performed well under far-field earthquakes, near-fault excitations significantly degraded their effectiveness. Balou et al. (2021) studied seismic fragility of LRB-isolated multi-span concrete arch bridges [16]. Results showed 67% and 64% reductions in longitudinal and transverse relative displacements, respectively, with LRBs reducing seismic fragility across damage levels. Despite extensive studies on LRBs and fragility analysis, no prior research has specifically addressed the seismic performance of mid-rise concrete buildings equipped with LRBs using fragility curves. This study fills this gap by evaluating 8- and 12-story concrete frames, providing novel insights into height-

2. METHODOLOGY

In this study, two mid-rise concrete buildings 8 and 12 story intermediate moment-resisting frames were analyzed. The structures, located in Tehran, Iran,

feature a regular geometric layout with uniform story heights of 3.0 m, resulting in total heights of 24 m (8-story) and 36 m (12-story). Both buildings have

symmetrical plans ($15\text{ m} \times 15\text{ m}$) with three 5.0 m spans in the longitudinal and transverse directions (Figure 1).

The structural models were developed in SAP software, and a representative frame (located on Gridline 2) was extracted for detailed 2D nonlinear modeling in OpenSees. Ten near-field earthquake records were selected from the PEER (Pacific Earthquake Engineering Research) database. Selection criteria prioritized avoiding resonance phenomena by evaluating time-history velocity and displacement profiles. Table 1 summarizes the

earthquake records, including moment magnitude (M), peak ground acceleration (PGA), and peak ground velocity (PGV).

Loading conditions were defined as follows:

-Dead Load: 230 kg/m^2 on floors, 300 kg/m^2 on the roof.

-Snow Load: 50 kg/m^2 applied to the roof.

Slab self-weight was automatically calculated and applied by the software. All supports were modeled as fixed, and effective seismic mass was defined as 100% of dead load + 20% of live load.

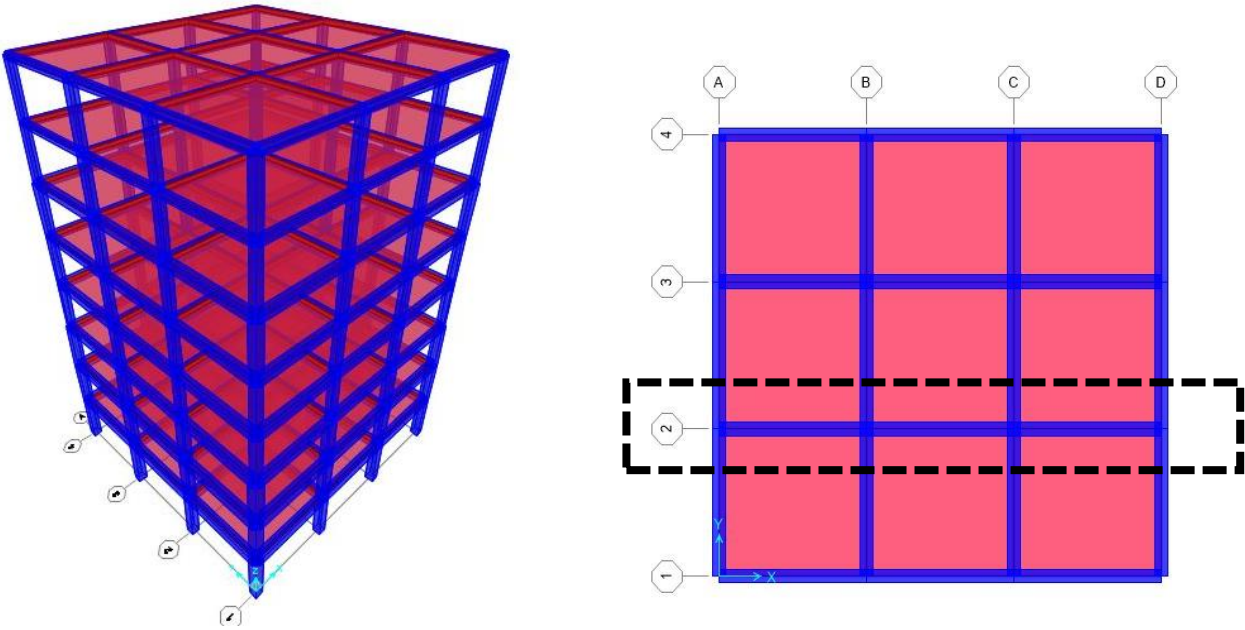


Figure1. Three-Dimensional (3D) View of the 8- and 12-Story Structures and Location of the Selected Frame from the Analyzed Models.

Table 1. Earthquake Records Utilized in the Study.

Earthquake Name	Year	PGV (cm/s)	PGA (g)	Moment Magnitude (M)
Imperial Valley (Array #06)	1979	111.9	0.44	6.5
Loma Prieta (Saratoga)	1989	55.6	0.38	6.9
Landers (Lucerne)	1992	140.3	0.79	7.3
Erzincan	1992	95.5	0.49	6.7
Northridge (Sylmar)	1994	122.8	0.73	6.7
Kocaeli (İzmit)	1999	29.8	0.22	7.5
Chi-Chi (TCU065)	1999	127.7	0.82	7.6
Northridge (Rinaldi)	1994	167.3	0.87	6.7
Irpinia (Sturmo)	1980	45.5	0.31	6.9

- PGV (Peak Ground Velocity): Maximum ground velocity during an earthquake (cm/s).
- PGA (Peak Ground Acceleration): Maximum ground acceleration during an earthquake (g).
- M (Moment Magnitude): Measure of earthquake size based on seismic moment.

Note: Earthquake names include specific recording stations or regions in parentheses. Data sourced from the PEER (Pacific Earthquake Engineering Research) database.

2.1. LRB Design Procedure

The Lead Rubber Bearings (LRBs) were designed based on the following steps:

1.Target Period Assumption:

A target fundamental period (TD) was assumed for the isolated structures.

2.Effective Stiffness Calculation:

The effective stiffness (Keff) of the LRB system was computed using Equation (3):

$$k_{eff} = \frac{W_{DL} + 0.2LL}{g} \times \left(\frac{2\pi}{T_D}\right)^2 \quad (3)$$

where:

W=Dead Load+0.2×Live Load

g=gravitational acceleration

3.Design Displacement Determination:

The design displacement (Dd) at the isolation system's stiffness center was calculated using Equation (4):

$$D_D = \frac{g}{4\pi^2} \times \left(\frac{S_{1D}T_D}{B_{1D}}\right)^2 \quad (4)$$

where:

S_{1D}: Spectral acceleration coefficient at TD,

B_{1D}=1.6: Damping coefficient corresponding to a damping ratio of 25%.

4.Post-Yield Stiffness Estimation:

The post-yield stiffness (Kp) was derived using Equation (5):

$$k_p = k_{eff} - \frac{Q_D}{D_n} \quad (5)$$

$$Q_D = \frac{W_D}{4D_n} \quad (6)$$

where QD (characteristic strength) is calculated again via Equation (7):

$$Q_D = A_{pb} \times F_{ypb} \quad (7)$$

5.Yield Stress Calculation:

Yield stress (σy) was determined using assumptions from Equations (8) and (9), leading to Equation (10):

$$k_s = 10k_d \quad (8)$$

$$D_y = \frac{Q_D}{k_s - k_p} \quad (9)$$

$$F_y = Q_D + k_p \times D_y \quad (10)$$

6.Elastic Stiffness Derivation:

The elastic stiffness (Ke) of the LRB was finalized using Equation (11):

$$k_s = \frac{F_y}{D_y} \quad (11)$$

Where Dy is the yield displacement of the LRB.

Design Parameters:

All LRB specifications (e.g., dimensions, shear modulus, damping ratios) were adopted from the FIP Industrial (Italy) catalog.

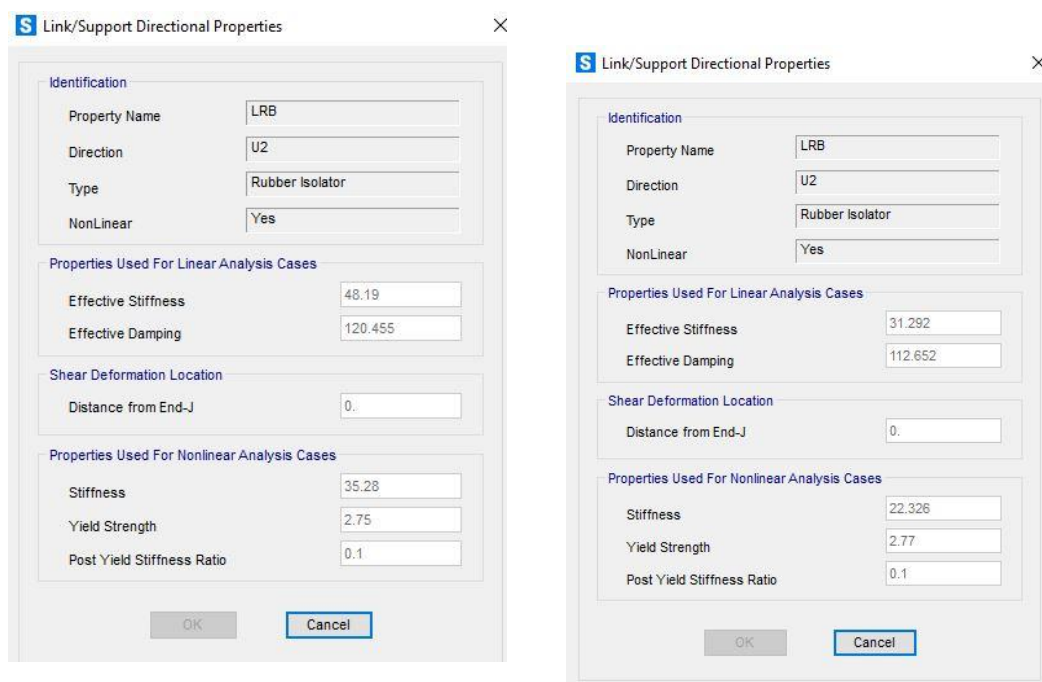


Figure 2. Allocation of Numerical Parameters for LRB Modeling in the 8-Story (UP) and 12-Story (DOWN) Structures

2.2. Structural Modeling

Beams/Columns: Reinforced concrete sections (e.g., C80×80 with 20T20 rebars for columns; B60×60 for beams).

Material Properties:

Concrete: $f_c' = 30 \text{ MPa}$ a $f_c' = 30 \text{ MPa}$, cracking coefficients = 0.7 (columns), 0.35 (beams), 0.25 (slabs).

Reinforcement: AIII (longitudinal), AII (stirrups).

Boundary Conditions: Fixed supports; seismic mass = 100% dead load + 20% live load.

Load Combinations: ACI 318-19 compliant, including dead, live, snow, and seismic loads (30-100 rule for eccentricity).

2.3. Analysis Protocol

1. Nonlinear Modeling: OpenSees for 2D frame analysis with fiber sections.

2. Incremental Dynamic Analysis (IDA): Conducted using 10 scaled ground motions to derive fragility curves.

3. Performance Limits: Inter-story drift ratio thresholds (IO = 0.7%, CP = 2.5%) per ASCE/SEI 41-17.

2.4. Verification

2.5. Structural Modeling Validation

To validate the SAP modeling approach, a two-story, single-bay RC frame tested by Taghavi et al. [17] was replicated. The experimental model featured 30×40 cm beams/columns reinforced with 4×Ø20 longitudinal bars and Ø10 stirrups spaced at 125 mm. Concrete properties included $f_c' = 30 \text{ MPa}$, ultimate stress = 596 MPa, and modulus of elasticity = 192,500 MPa. A vertical load of 700 kN and triangular lateral load (1000 kN at the second floor) were applied. Figure 3 compares the force-displacement hysteresis curves from the experimental study and the SAP model, showing a 3% maximum discrepancy, confirming modeling accuracy.

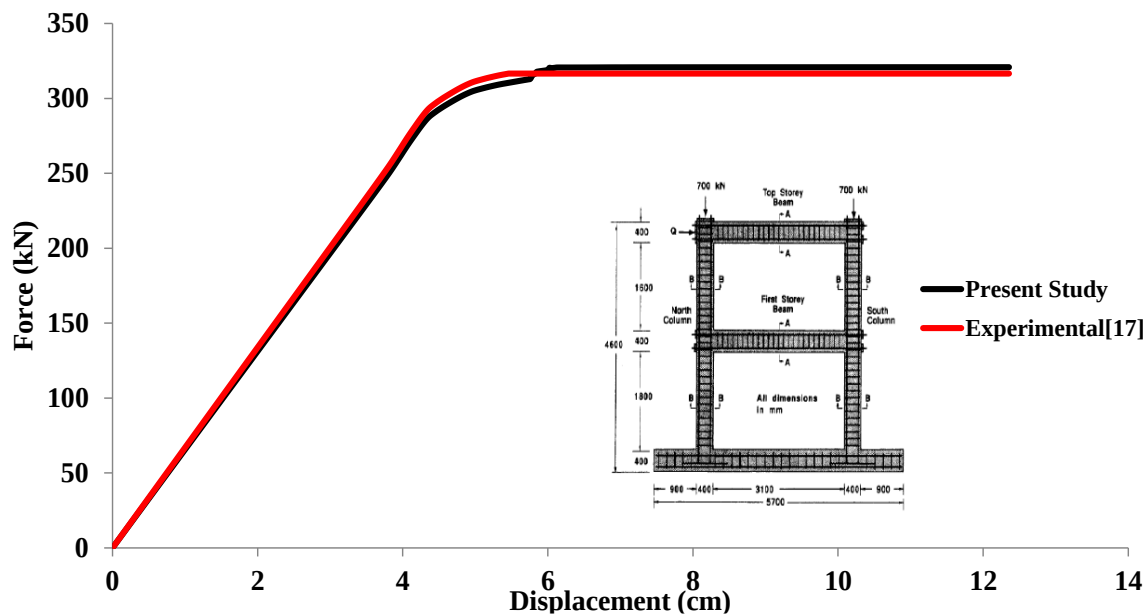


Figure 3. Force-displacement hysteresis curves for validation

2.6. LRB Modeling Validation

The LRB modeling methodology was validated against Seifi and Rafiei's [18] 10-story dual-system (MRF + shear wall) building on Type II soil (per Iranian Standard 2800). Columns (e.g., C550×500-12T25) and beams (e.g., B500×400) were analyzed

under near-fault records. Base shear comparisons (Figure 4) revealed a 3.6% maximum deviation between the SAP model and reference results, validating the LRB modeling approach.

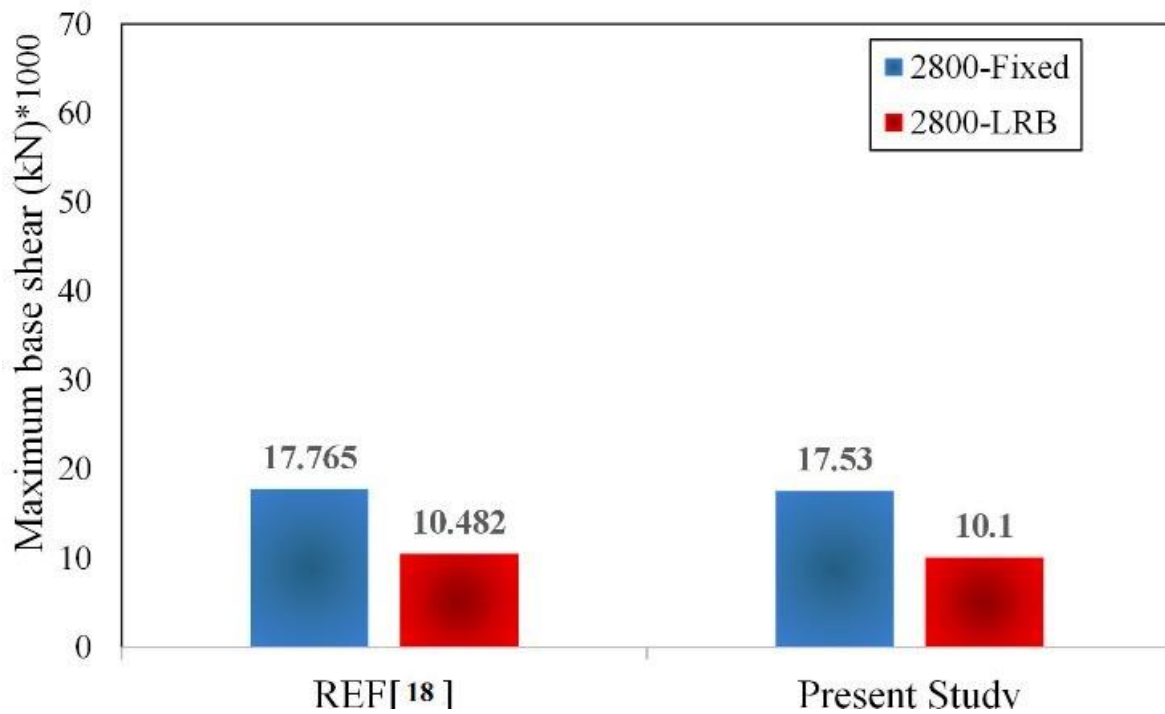


Figure 4. Base shear validation for the LRB-isolated 10-story building

3. RESULTS AND DISCUSSION

The 8- and 12-story structures investigated in this study were initially modeled and analyzed/designed using SAP2000 software. Subsequently, the impact of implementing base isolators on the design outcomes and the periods of the first four vibrational modes of the structures was evaluated. It is noteworthy that incremental dynamic analysis (IDA) was performed on selected two-dimensional frames (Frame 2-axis). Figure 5 illustrates the designed cross-sections and stress ratios in the members of the 8-story frame with and without base isolators. Similarly, Figure 6 presents the designed cross-sections and stress ratios for the 12-story frame with and without base isolators. As observed, the incorporation of base isolators altered both the cross-sectional designs and the induced stress ratios in the structural members. This modification is evident in both the 8- and 12-story frames. The design process ensured that stress ratios remained within permissible limits across all sections of the studied frames. Based on the IDA results, drift parameters were derived for varying peak ground acceleration (PGA) levels of the applied seismic records to the frames. Utilizing the drift parameters corresponding to four damage states (as per HAZUS guidelines for frames ≥ 8 stories), fragility curves were generated using EasyFit software. Importantly, the TREND

command was employed to determine the PGA values associated with each damage state.

3.1. Period Comparison

The first four modal periods of the 8- and 12-story frames with/without LRBs are compared in Figure 7. Key findings: •8-story frame: LRBs increased periods by $2.22\times$ (Mode 1), $2.22\times$ (Mode 2), $2.19\times$ (Mode 3), and $1.52\times$ (Mode 4).

•12-story frame: Periods increased by $2.17\times$ (Mode 1), $2.17\times$ (Mode 2), $2.1\times$ (Mode 3), and $1.54\times$ (Mode 4). LRB effectiveness in period elongation diminishes in higher modes and is more pronounced in shorter buildings.

3.2. Incremental Dynamic Analysis (IDA) Results

Following the modelling and design of three-dimensional 8- and 12-story intermediate concrete moment frames (with and without lead rubber bearings, LRBs) in SAP2000 software, the selected frame (located on Axis 2) was extracted, and 10 scaled accelerograms were applied to the models. The LRBs were developed based on a bilinear force-displacement hysteresis response, with nonlinear parameters defined according to specifications provided by FIP Industries. Incremental Dynamic Analysis (IDA) was subsequently conducted to extract the maximum inter-story drift ratio for

incremental PGA steps (10 steps). Earthquake records are scaled with an incremental step of 0.1 PGA for IDA analysis. The obtained drift values, aligned with the damage state criteria outlined in the HAZUS guidelines, were processed to generate fragility curves. In this study, fragility curves were derived using the relative lateral drift ratio (inter-story drift) as the damage index.

Per the HAZUS guidelines for buildings ≥ 8 stories, the drift ratios corresponding to four damage states are defined as follows:

- Slight Damage: 0.0025
- Moderate Damage: 0.005
- Extensive Damage: 0.015
- Complete Collapse: 0.04

Figure 8 presents the IDA results for the 8-story frame with and without LRBs, while Figure 9 illustrates the IDA results for the 12-story frame under both conditions. In all IDA plots, the horizontal axis represents the maximum relative lateral drift (in percentage), and the vertical axis denotes the peak ground acceleration (PGA) normalized to gravitational acceleration (g).

A comparison of the IDA curves reveals that the incorporation of LRBs reduced the inter-story drift parameter in both 8- and 12-story frames. For the 8-story frame, the average reduction in inter-story drift due to LRBs was 14.3%, whereas the 12-story frame exhibited an 18.5% reduction. These results indicate that the effectiveness of LRBs in mitigating inter-story drift improves with increasing structural height. Specifically, taller frames demonstrate a higher rate of LRB efficacy in reducing drift responses.

It is important to note that the presented results reflect averaged values derived from the application of 10 seismic records for fragility curve development.

IDA curves (Figures 8–9) demonstrate LRB effectiveness in reducing inter-story drift:

- 8-story: Average drift reduction = 14.3% (max PGA = 0.82g).
- 12-story: Average drift reduction = 18.5% (max PGA = 0.87g).

Taller structures exhibit greater LRB efficacy due to enhanced flexibility and damping.

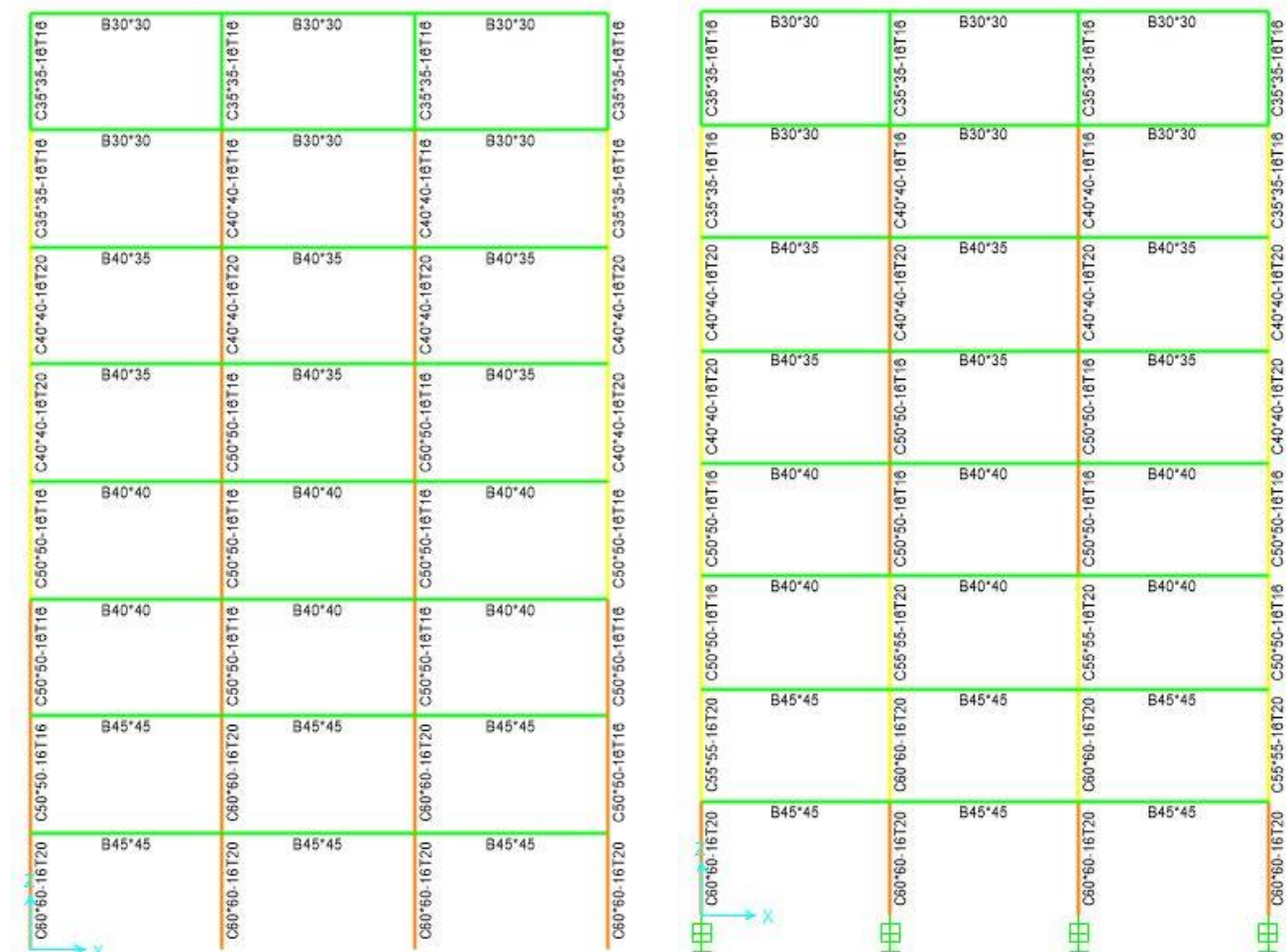


Figure 5. Designed cross-sections in the selected frame of the 8-story structure with and without base isolators.

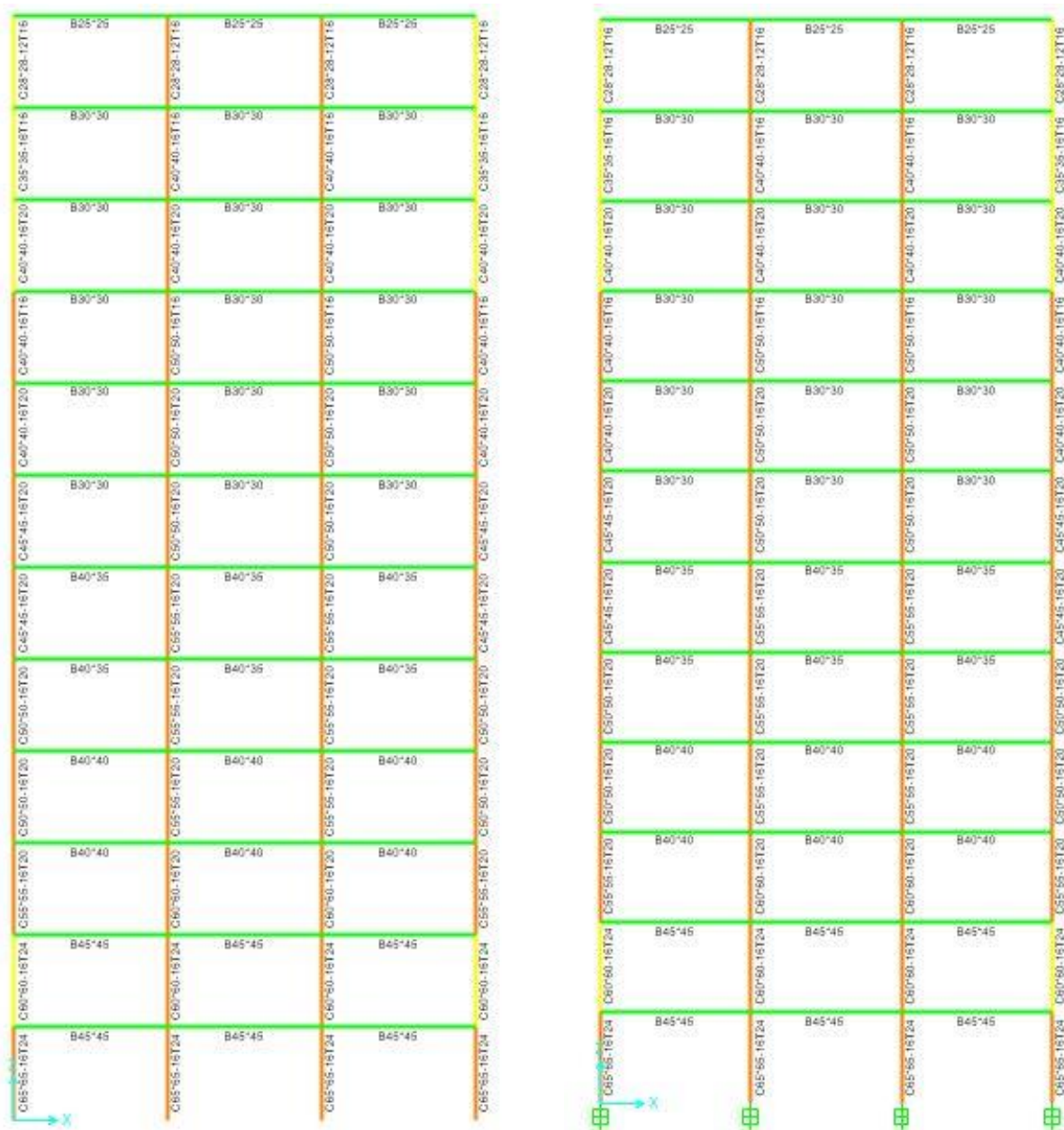
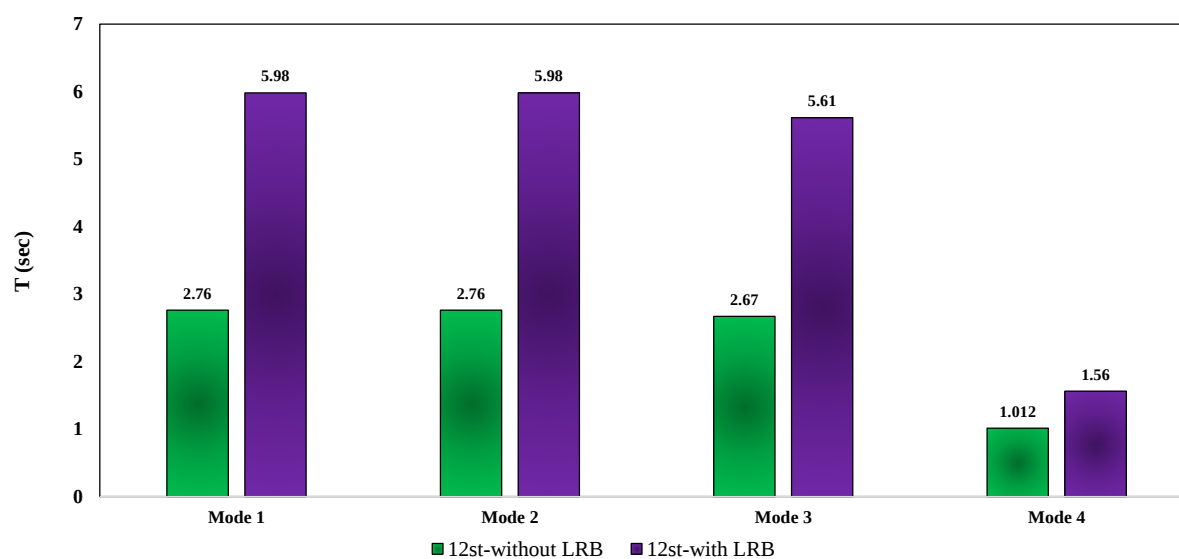


Figure 6. Designed cross-sections in the selected frame of the 12-story structure with and without base isolators



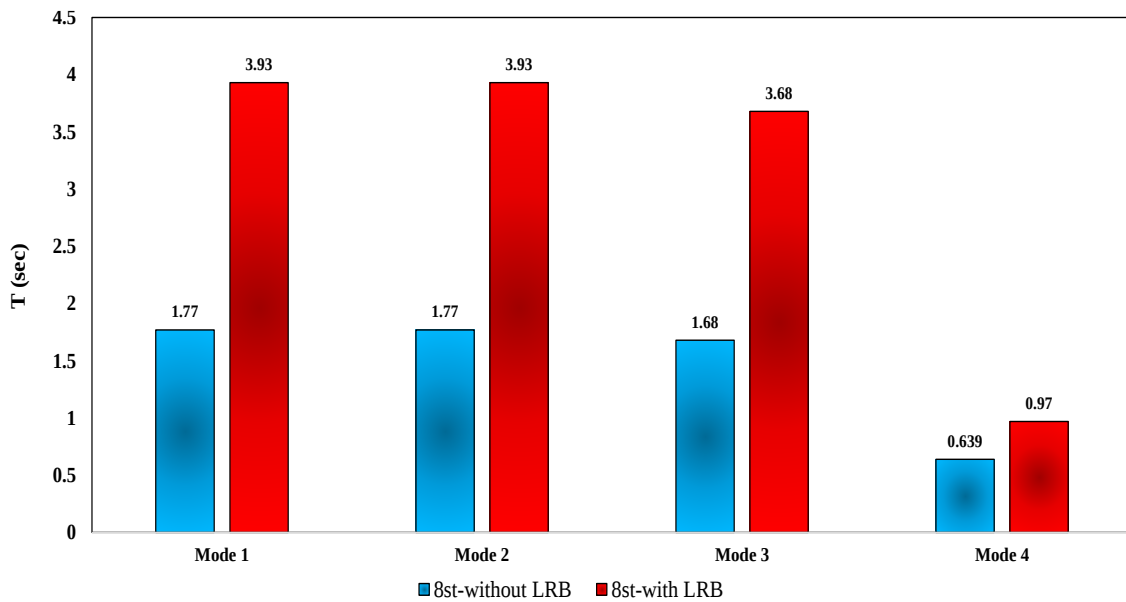


Figure 7. LRB impact on structural periods for 8- and 12-story frames

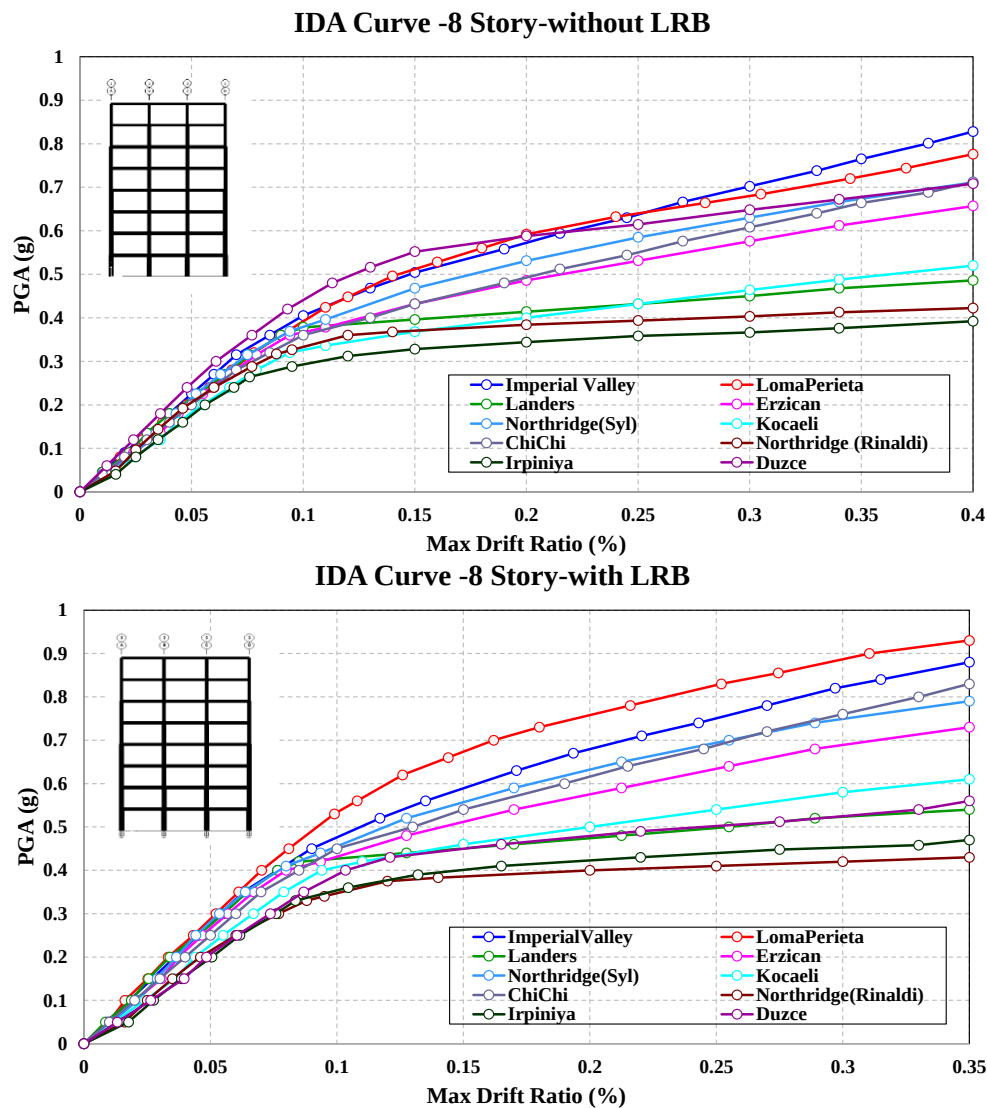


Figure 8. IDA curves for the 8-story frame with/without LRB.

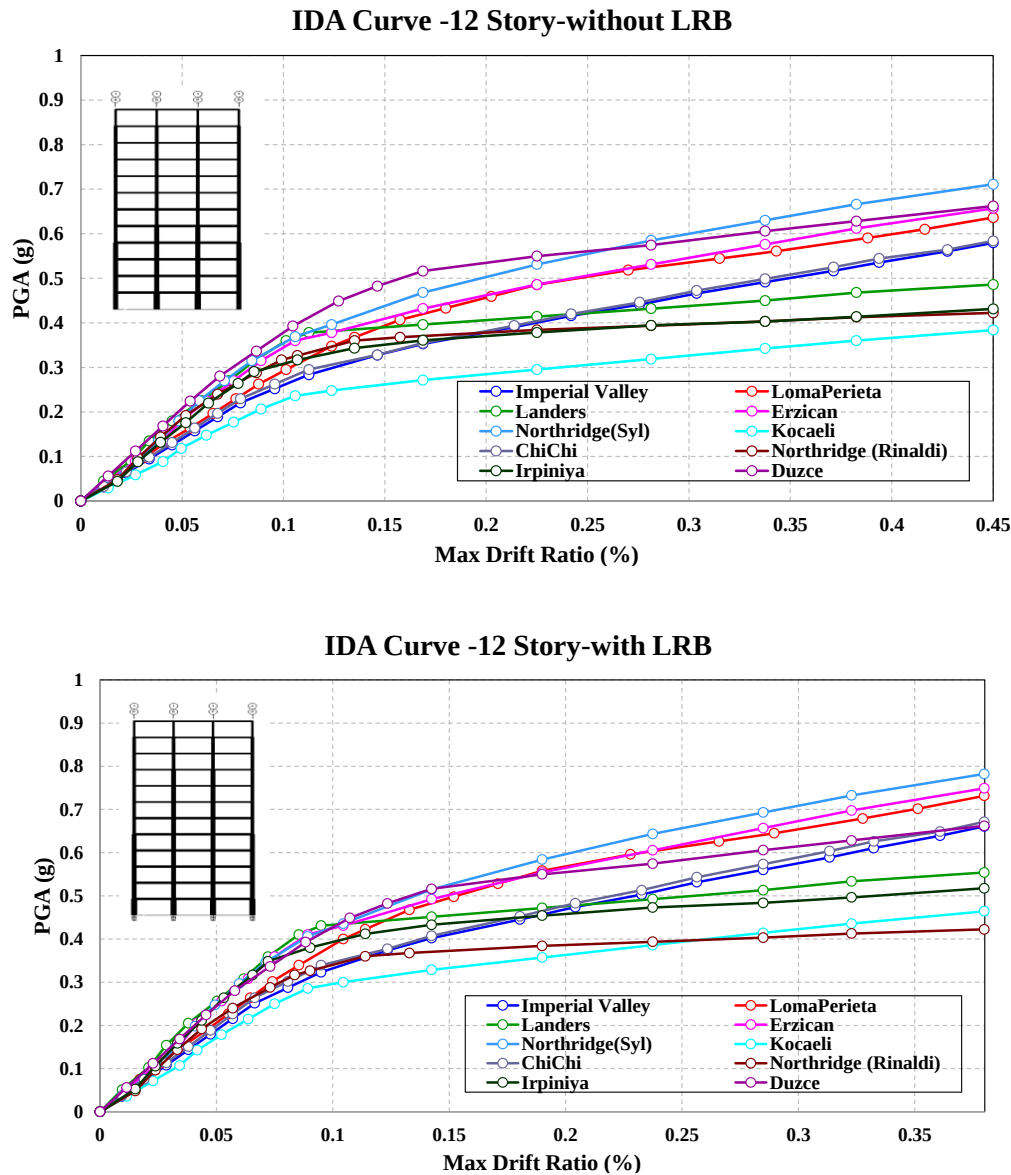


Figure 9. IDA curves for the 12-story frame with/without LRB.

3.3. Fragility Analysis

Figure 10 illustrates the fragility curves for the 8-story concrete moment frame with and without lead rubber bearings (LRBs). In the fragility curves, the horizontal axis represents peak ground acceleration (PGA), while the vertical axis denotes the probability of exceedance. The results for the 8-story frame demonstrate that incorporating LRBs into the structural system reduces the probability of seismic damage. Specifically, the maximum probabilities of slight, moderate, extensive, and complete damage states for the 8-story frame without LRBs occur at PGAs of 0.06g, 0.106g, 0.16g, and 0.18g, respectively. In contrast, for the 8-story frame with LRBs, these damage states are reached at higher PGAs of 0.088g, 0.117g, 0.259g, and 0.297g, respectively. This indicates that the LRB-equipped frame exhibits enhanced stability, requiring significantly larger PGAs to reach the thresholds of

the four damage states. A critical observation is the reduction in exceedance probability (likelihood of damage occurrence) from 0.995 (without LRBs) to 0.89 (with LRBs) for the 8-story frame. In other words, the use of LRBs reduces the probability of seismic damage in the 8-story frame by 11.8% compared to the non-isolated structure. Figure 11 presents the fragility curves for the 12-story concrete moment frame with and without lead rubber bearings (LRBs). In the fragility curves, the horizontal axis represents peak ground acceleration (PGA in term of "g"), and the vertical axis denotes the probability of exceedance. The results for the 12-story frame indicate that incorporating LRBs into the structural system significantly reduces the likelihood of seismic damage. Specifically, the maximum probabilities of slight, moderate, extensive, and complete damage states for the 12-story frame

without LRBs occur at PGAs of 0.013g, 0.023g, 0.07g, and 0.095g, respectively. In contrast, for the LRB-equipped 12-story frame, these damage states are reached at substantially higher PGAs of 0.085g, 0.1g, 0.175g, and 0.19g, respectively. This demonstrates that the integration of LRBs enhances the structural stability of the 12-story frame, requiring larger seismic excitations to trigger the four defined damage thresholds. A critical observation is the reduction in exceedance probability (likelihood of damage occurrence) from 0.998 (without LRBs) to 0.8 (with LRBs),

representing a 24.75% decrease in the probability of seismic damage for the 12-story frame. In summary, the use of LRBs in both 8- and 12-story frames reduces the probability of exceedance and seismic damage, with the mitigation effect being more pronounced in the taller 12-story frame. These findings suggest that the efficacy of LRBs in reducing seismic vulnerability improves with increasing structural height. Specifically, taller frames exhibit a higher rate of LRB effectiveness in lowering both inter-story drift and damage probability.

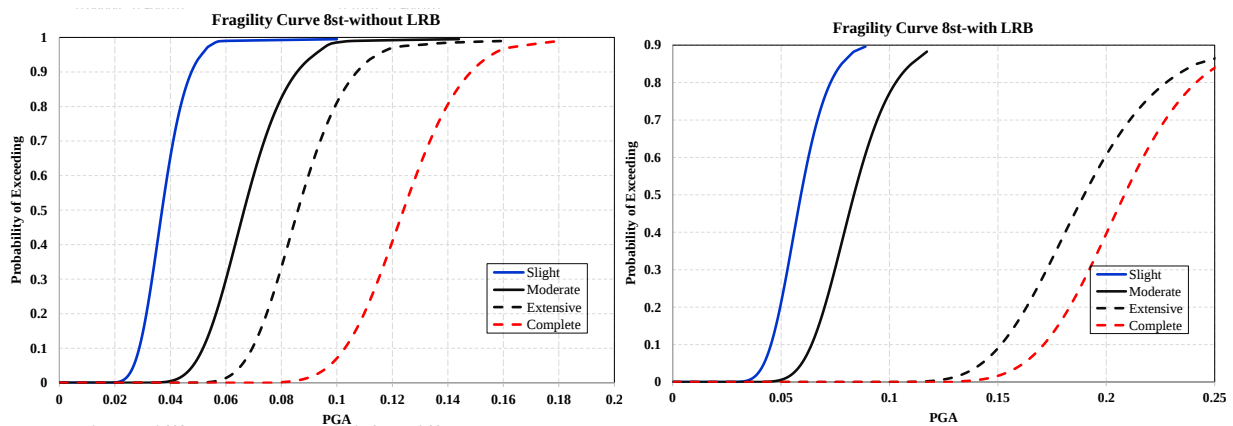


Figure10. Fragility curves for the 8-story frame (PGA in term of "g")

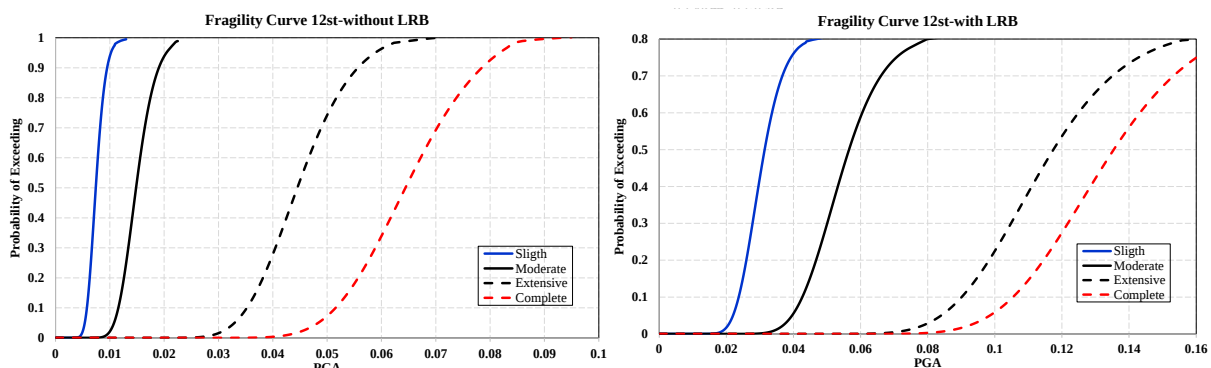


Figure11. Fragility curves for the 12-story frame PGA in term of "g")

Fragility curves (Figures 10–11) were derived using HAZUS damage thresholds:

- Slight: Drift = 0.25%, Moderate: 0.5%, Extensive: 1.5%, Complete: 4.0%.

Key Results:

- 8-story:

- Without LRB: Peak failure probabilities at PGA = 0.06g (slight), 0.106g (moderate), 0.16g (extensive), 0.18g (complete).

- With LRB: Failure probabilities reduced by 11.8%, with thresholds shifted to PGA = 0.088g, 0.117g, 0.259g, and 0.297g.

- 12-story:

- Without LRB: Peak failure probabilities at PGA =

- 0.013g (slight), 0.023g (moderate), 0.07g (extensive), 0.095g (complete).

- With LRB: Failure probabilities reduced by 24.75%, with thresholds shifted to PGA = 0.085g, 0.1g, 0.175g, and 0.19g.

- 1.LRBs increased structural periods by 2.17–2.22× in lower modes, enhancing seismic isolation.

- 2.Drift reductions of 14.3% (8-story) and 18.5% (12-story) confirm LRBs' efficacy in mitigating seismic demand.

- 3.Damage probability decreased by 11.8% (8-story) and 24.75% (12-story), highlighting superior LRB performance in taller buildings.

4. CONCLUSION

The key findings of this study are summarized as follows:

1. Period Elongation:

-The incorporation of LRBs at the base significantly increased the structural period of both 8- and 12-story buildings. The amplification was most pronounced in the first two modes, with period increases of $2.22\times$ (8-story) and $2.17\times$ (12-story) for Mode 1. Higher modes exhibited diminishing effects, confirming LRBs' superior efficacy in lower vibration modes.

2. Inter-Story Drift Reduction:

-LRBs reduced average inter-story drift by 14.3% (8-story) and 18.5% (12-story), as evidenced by IDA curves. The taller 12-story frame demonstrated greater drift mitigation, highlighting LRBs' enhanced performance in high-rise configurations. The use of LRB improve seismic resilience in high-rise structures in Iran.

3. Enhanced Seismic Stability:

-LRB-equipped frames tolerated significantly higher PGA thresholds before reaching damage states (slight, moderate, extensive, complete). For instance, the 12-story frame with LRBs resisted PGA values up to 0.19g for complete collapse, compared to 0.095g for the fixed-base counterpart.

4. Damage Probability Reduction:

-LRBs reduced the probability of damage exceedance by 11.8% (8-story) and 24.75% (12-story). The taller structure exhibited nearly double the improvement, underscoring LRBs' scalability for mid- to high-rise buildings.

5. Height-Dependent Efficacy:

-LRB performance improved with building height, as taller structures benefited more from period elongation and energy dissipation. This trend emphasizes LRBs' suitability for urban high-rise developments in seismically active regions.

Practical Implications

These findings advocate for the widespread adoption of LRBs in mid-rise concrete buildings, particularly in earthquake-prone areas like Iran. Designers should prioritize LRB integration in taller structures to maximize seismic resilience, reduce economic losses, and enhance life safety. Future work should explore LRB-soil-structure interaction effects and near-fault ground motion impacts.

In this study, only two structures (8& 12 story) were investigated, so that results of this study are also valid for high-rise structures with other stories. Soil-Structure Interaction is outside the scope of the present study.

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UTHORS CONTRIBUTION

This work was carried out in collaboration among all authors.

ONFLICT OF INTEREST

The author (s) declared no potential conflicts of interests with respect to the authorship and/or publication of this paper.

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